

COMPARATIVE STUDY OF SIGNAL DETECTION TECHNIQUES IN MU-MIMO

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ABSTRACT

MU-MIMO is widely used over SU-MIMO due to high MIMO capacity gain, immense SNR along with great throughput, multiple user equipments and BS can have simultaneous connections and therefore, data rate improvisation that is spectral efficiency without affecting reliability of the system. Nonetheless, due to spatial multiplexing and increase in number of user equipments, complexity of signal detection increases too. In previous researches, suboptimal and optimal detection techniques such as ZF, MMSE and ML with low complexities are used for signal detection in SU-MIMO only. This paper proposes a system which used to analyse and compare the above mentioned detection techniques for MU-MIMO, where spatial multiplexing is used. The limitations of practical multiplexing gain in MU-MIMO system is overcome by spatial correlation to detect, mitigate or avoid weak channel gains.

KEYWORDS: MU-MIMO, Signal Detection, ZF, MMSE, ML, Spatial Multiplexing

INTRODUCTION

MU-MIMO is an advanced state of MIMO technology which enables spatial multiplexing in which multiple independent and distributed encoded data streams from every transmitter [1]. Hence, space range is reused or diversified. MUMIMO provides increased data rate and improved stability due to spatial multiplexing and diversity respectively. Spatial multiplexing in multiuser systems is to weaken the interference introducing from nearby cells [2]. For uplink, MU-MIMO is categorized as Broadcast Channels (MIMO BC) and Multiple Access Channel (MIMO MAC) for MIMO downlink. It drastically improves performance of the MIMO system as numerous equipments could communicate simultaneously using same spectrum [2]. Forthcoming wireless networks are ultimately expected to take up multiuser MIMO system, whose condition is achieved to higher level by using precoding technique at transmitter [5]. Nonetheless, multiuser MIMO primitively antenna with Frequency-Division Duplex (FDD) employment but it comes with complexities as FDD operation have nonscalable approach [5]. In MU-MIMO, the signaling overhead requirement is high, since there are multiple user equipments at receiver side for single base station. Hence, channel matrix coefficients increases along with the product of transmit antenna coefficients [6].

To overcome basic needs and challenges like less power consumption, bandwidth reuse, low complexity of the system data rate increment and huge capacity; much research is done in the cognitive radio techniques, space relaying, co-operativenet works, adaptive cross-layer method and co-ordinated multipoint(CoMP) [6]. Considering the previous research done in MIMO area, it indicated the chances of advancement in bandwidth

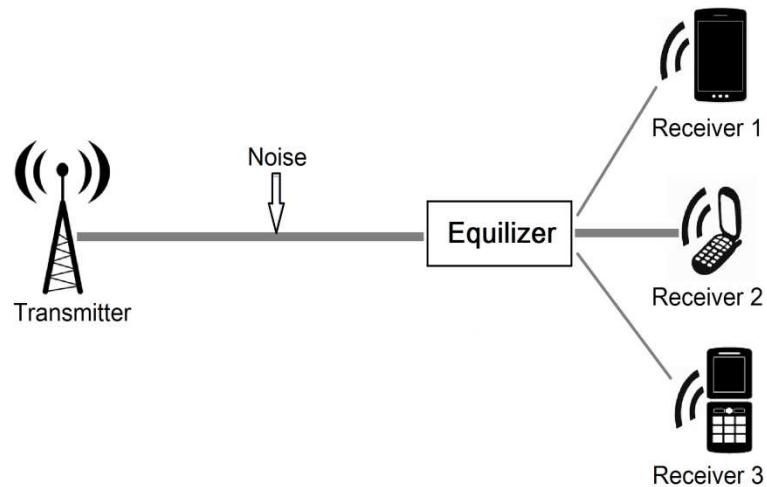


Figure 1: Multiuser Detector

Reuse, channel improvement and spectral efficiency [7] MU-MIMO have become an essential factor of communication standards like Long Term Evolution (LTE), WiFi (802.11), WiMAX (802.16) and consecutively being implemented in many applications all over the world [7]. Signal detection is nothing but to discover transmitted data from gathered receiver data under evaluated CSI. Channel condition and quality is explained by the CSI which is beneficial for fidelity adaption and remodeling along with boosted data rate in presence of multipath and interference [3]. Bell Laboratories Layered Space-Time (BLAST) MIMO system has proved that the execution and complexity differences between the linear and non-linear detectors are used in BLAST system are massive, which keeps significantly vast improvement space [3]. In communication, there is addition of noise in channel before transmitted information reaches to the receiver [4]. Equalization system comes before the receiver as shown in figure 1 and to compensate transmitted channel signal distortions such as phase, amplitude and frequency distortions.

Being the crucial technology of modern era of communication, signal detection in MU-MIMO has been designed voluminously and many signal detection techniques has been proposed. They are classified as linear and non-linear signal detectors. Linear detection techniques normally accomplish feasible performance with reduced complexity where nonlinear techniques are proved as great capacity achieving methods. The paper alignment is as follows: section 2 describes system model of proposed technique of signal detection at receiver in MU-MIMO, section 3 lightens the multiplexing theory for the detection. Section 4 discusses simulations and compares detection schemes using system performance and final section plots the conclusion of proposed work.

SYSTEM MODEL

Figure 2 represents the proposed MU-MIMO signal detection system model. This block diagram follows spatial multiplexing scheme, where main generated data streams are split into separate and independent divided streams for each transmit terminal available in the system. Because of spatial multiplexing, this organization contributes to spatial gain and spectral efficiency. The demand of spatial multiplexing is a robust decoding at the receiver. For this scheme, we are using three separate kind of receivers ZF, MMSE and ML. Proposed detection model is somewhat similar to the Vertical-Bell Laboratories Layered Space-Time (V-BLAST) [12] technique. For interpretive merits, the system model considers different receivers with various antenna configurations. Antenna configurations used for simulation are 2x2, 3x3, 4x4 and 8x8; so that it will be easy for comparative analysis. Phase Shift Keying (PSK) modulation method selected for this model

and constellation size is taken as of order 2. It uses flat Rayleigh fading for employment on spatially multiplexed independent antenna links. For better realization, we have assumed that receivers has knowledge of channel and it is not giving feedback. Hence, it is not a closed-loop system. Channel is considered as error-free and receive array gain is ignored in the system.

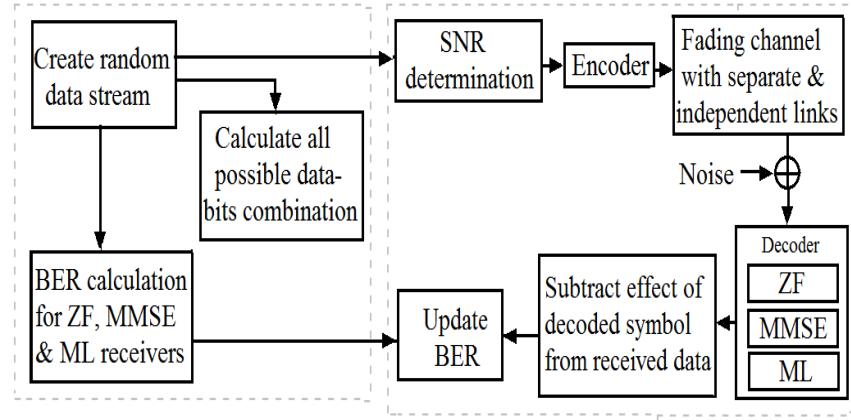


Figure 2: Signal Detection Model for MU-MIMO

The system model is mainly divided into two parts. First one is generation part, where we create and set up all basic required parameters and second part shows actual system operation. In generation and set up module, any number of transmitter and receiver antennas with fixed SNR range and constellation size for modulation. A generated random data stream provided to a modulator. At same time, all possible combinations of generated data bits are calculated for maximum likelihood receiver. BER calculation is done for used receiver kinds, that are ZF, MMSE and ML receivers.

SNR is determined from the Eb/No for every independent spatial links and BER is adapted. After encoding all data symbol vectors, noise is added to faded data. At the receiver end, decoding process takes place. Decoder block consists of optimal and suboptimal receivers as drawn in model. At this stage, channel matrix gets diminished to remove signs of previously decoded symbol. Finally, the effect of symbols which are decoded, subtracted from acknowledged data symbols with new data bits. Similar to V-BLAST technique, this will leads to the next uttermost signal detection, which also nullifies the bit error rate over a given channel [12]. Unlike STBC (Space-Time Block Coding), this model does not needed explicit orthogonalization. Simulations are done using this proposed system for ZF, MMSE and ML receivers using PSK modulation technique and executed for 2x2, 3x3, 4x4 and 8x8 antenna configurations. Detailed discussion on this is provided in section 4.

SIGNAL DETECTION TECHNIQUES

Linear detectors such as Matched Filter (MF), Zero Forcing(ZF) and Minimum Mean Square Error (MMSE) amplifies the interference then the detector channel matrix become approximately singular, hence, linear detectors shows poor performance. Opposite to it, non-linear detector like Maximum Likelihood (ML) does not shows noise amplification since the channel matrix has orthogonal nature [8]. In this section, the types of signal detection methods used in this paper will be described. As MF technique is generally used for SUMIMO, we have not considering it for comparative analysis. ZF and MMSE are suboptimal techniques for MU-MIMO signal detection and ML is considered as optimal technique.

- **ZERO FORCING DETECTION (ZF)**

ZF is the simplest MU-MIMO detection method [8], which without much complexities inverts the channel matrix. This is a linear type of method in which it is needed to assume that the base station (BS) has knowledge of perfect channel state information (CSI) of all user equipments present at the receiver side [13]. ZF detector can easily deal with interference if BS antennas are present immensely, then channel vectors become closely orthogonal by inverting the channel matrix. ZF technique removes approximately complete inter-symbol interference (ISI) and for noiseless channels, it is ideal.

$$z = H_b^* = H^T H^{-1} H^T b \quad (1)$$

Here the pseudo-inverse of MU-MIMO channel matrix H is denoted by H^* . After determining ZF matrix, the nearest point in δ for each symbol acquisition takes place independently. It is given by formula -

$$\hat{a}_i = \arg \min_{a_i \in \delta} \|z_i - \delta\| \quad (2)$$

This ZF algorithm performs inadequately due to its inefficiency of handling ill-conditioned executions of the channel matrix H .

- **Minimum Mean Square Error Detection (MMSE)**

MMSE suboptimal multiuser detection, considering Additive White Gaussian Noise (AWGN) and non-orthogonal environment [19]. Performance analysis of MMSE detector shows Multiple Access Interference (MAI) nature. This low complexity detection technique shows better performance than decorrelating detection of distributed cross correlation.

$$E(a|b) = (H^T H + \frac{\sigma^2}{E_s} I)^{-1} H^T b \quad (3)$$

Above equation shows Bayes estimation to acquire better MMSE performance in which E_s denotes the mean bit energy. The closest point in δ for each symbol independently determined by equation 4.

$$\hat{a}_i = \arg \min_{a_i \in \delta} \|E(a|b_i) - \delta\| \quad (4)$$

- **Maximum Likelihood Detection (ML)**

Maximum Likelihood detection used for measurement of the Euclidean distance between the shortest value from all the transmitted signal vectors and all the received signal vectors from channel matrix [13]. This technique has been proven best for reducing error probability (P_e). The simulation results obtained are best compared to all detection techniques. As number of antennas increases it shows abundant complexity as data streams are also large in MU-MIMO. ML generally used when SNR values are low [2][9]. Equation 5 shows maximum likelihood solution for measuring the shortest Euclidean distance.

$$\hat{a} = \arg \min_{a_i \in \delta^N} \|b - Hx\|^2 \quad (5)$$

Where δ^N stand for the possible symbols finite set in system.

PERFORMANCE ANALYSIS

This section gives a brief simulation analysis and description of proposed MU-MIMO linear and non-linear detection techniques. These simulations are done under MATLAB environment of MIMO toolbox. The functions used helps to plot the Bit Error Rate (BER) vs Eb/No (Energy per Bit) for comparison of different signal detection algorithms, that are ZF, MMSE and ML for 2x2, 3x3, 4x4 and 8x8 MUMIMO clearly shows how channel efficiency upgrades for detection technique with increase in number of antennas. The performance is carried out for fixed range of Signal to Noise Ratio (SNR) of 0 dB to 10 dB span (figure 3). As we are using PhaseShift Keying (PSK) modulation scheme, the provided constellation size is of order 2 with Rayleigh flat fading MIMO channel consideration. Accomplishment for three different receivers are done by examining under fixed and common specifications.

It is observed that, for all three detection mechanisms, 2x2 MU-MIMO system shows highest BER followed by 3x3 and 4x4. 8x8 is with lowest BER, hence performance become better when there is addition in antenna numbers (figure 3). By examining figures, we can state that, ML showing lowest bit error rate for all four antenna configurations and therefore, recorded best performance among considered signal detection algorithms

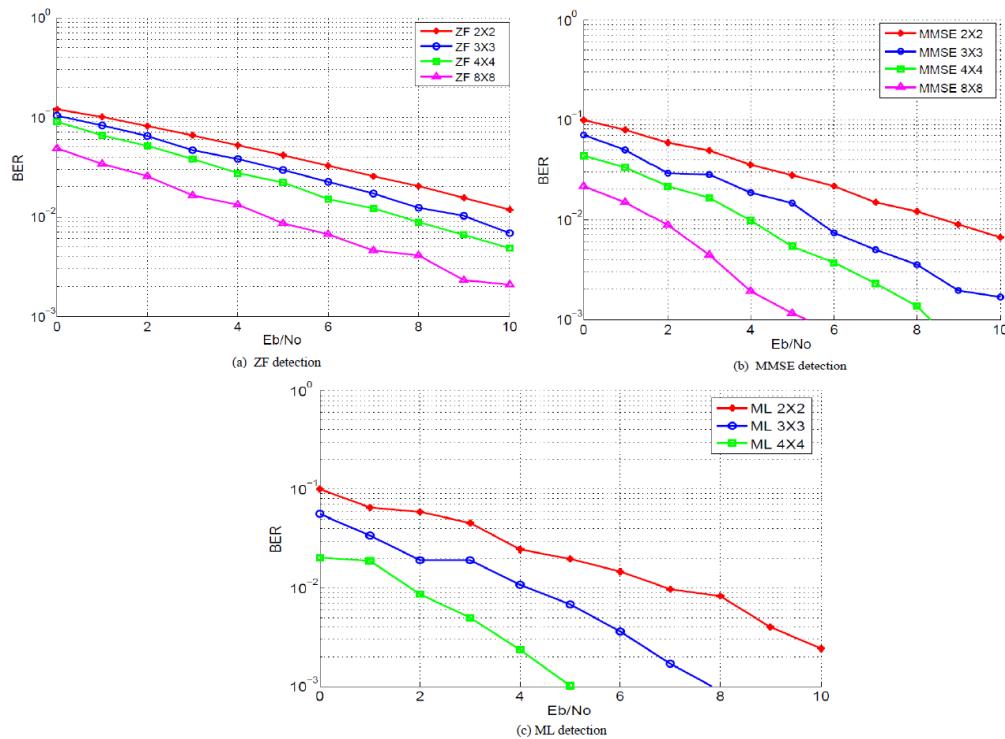


Figure 3: (A) ZF, (B) MMSE and (C) ML Detection for different MIMO Configurations

where ZF with highest BER values shows poor performance. Figure 4 represents precise simulation of BER performance for Eb/No values from 0-10 dB of each detection mechanism.

Figure 4 represents executions of suboptimal ZF, MMSE and optimal technique ML. Among these comparative graphs, figure 4(a) shows detection techniques for 2x2 configuration, where figure 4(b) and figure 4(c) represents 3x3 and 8x8 MIMO compositions respectively. When number of transmitters and receivers are taken as 2, in figure 4(a), we can see that compared to ZF, both MMSE and ML shows improved BER. The performance of receivers getting better with

increase in number of antennas in the system. 8x8 antenna system shows best detection results followed by 3x3 and 2x2. Also, we inspect that ML detection technique is the best among three detectors, where MMSE is better than ZF receiver, as also observed simulations. Considering method complexity, ML has maximum complexity where, ZF is straightforward one. Complexity will grow with number of antennas, so as receiver gain and capacity due to spatial multiplexing.

CONCLUSIONS

Fourth generation representative MU-MIMO is an upgraded form of MIMO technology which shows merits like more data rate, enhanced reliability, energy efficiency and interference reduction etc. This paper proposed a brief comparative study of optimal and sub-optimal detection techniques by spatial multiplexing on basis

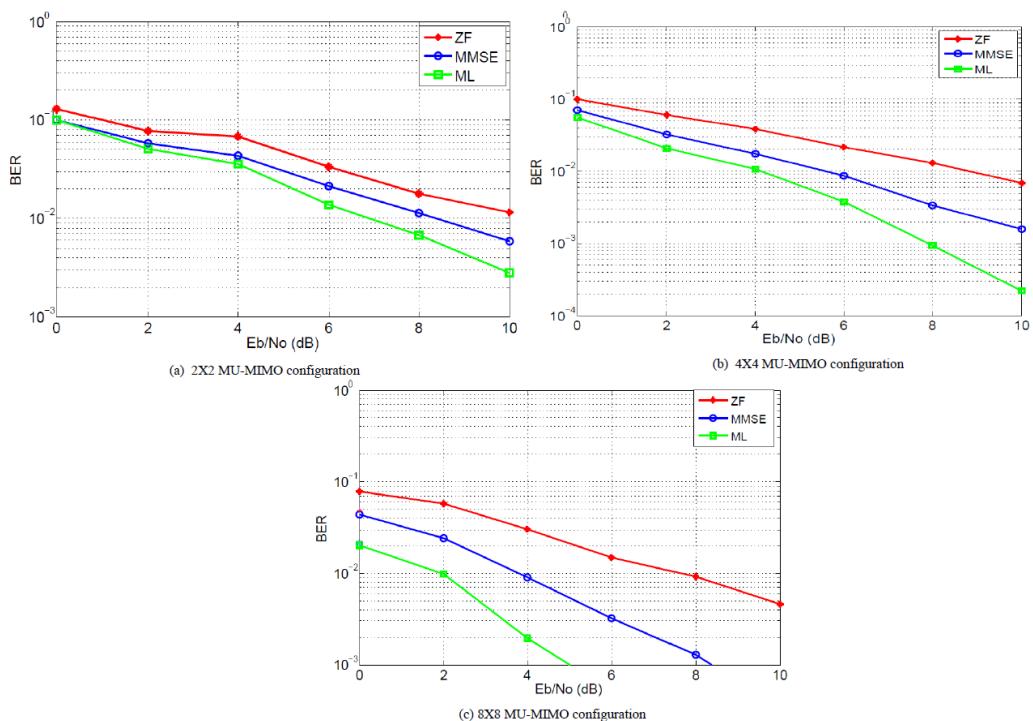


Figure 4: Comparison between ZF, MMSE and ML detection techniques for (a) 2X2, (b) 4X4 and (c) 8X8 MU-MIMO configurations

of characteristic parameters and determines the best and poor among them. Simulations are done for ZF, MMSE and ML detectors and result implied that, ML is most efficient and best detection technique followed by MMSE and ZF. Interference can be nullified due to spatial multiplexing and better results obtained than SU-MIMO by using proposed signal detection technique for MU-MIMO system.

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REFERENCES

1. Semih Serbetli, Aylin Yener, "Transceiver Optimization for Multiuser MIMO Systems," *IEEE Transaction On Signal Processing*, vol. 52, no. 1, January 2004.
2. Ben Zid Maha, Raoof Kosai, "Multi User MIMO Communication: Basic Aspects, Benefits and Challenges" available: <http://dx.doi.org/10.5772/57133>
3. G. J. Foschini, M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas" *Wireless Personal Communications*, 1998.
4. S. Karthikeyan, S. Sasikumar, et al, "Comparison of Linear and NonLinear Multi user Detectors with Quantum Constraints," *GESJ: Computer Science and Tele communications*, Vol. 26, No. 3, pp. 40-47, 2010.
5. E. G. Larsson, "Very Large MIMO Systems: Opportunities and Challenges", *Communication Systems Linkoping University*, March 2012.
6. Geoffrey Ye Li, Zhikun Xu, et al, " Energy-Efficient Wireless Communications: Tutorial, Survey, and Open Issues," *IEEE Wireless Communications*, December 2011.
7. "Introduction to MIMO", available: <http://rohde-schwarz.com>
8. Deric W. Waters, "Signal Detection Strategies and Algorithms for Multiple-Input Multiple-Output Channels", *Georgia Institute of Technology*, December 2005.
9. Ezio Biglieri, Robert Calderbank, et al, "Precoding design", *MIMO Wireless Communications*, Cambridge University Press, 2007.
10. Dr. Houman Zarrinkoub, "Overview of the LTE Physical Layer", *Understanding LTE with MATLAB*, John Wiley & Sons Pte Ltd, 2014.
11. Yong Soo Cho, et al, *MIMO-OFDM Wireless Communication with MATLAB*, John Wiley & Sons Pte Ltd, 2010.
12. Gerard. J. Foschini, "Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multi-Element Antennas", *Bell Laboratories Technical Journal*, pp. 41-59, October 1996.
13. H.Q. Ngo, et al, "Uplink performance analysis of multiuser MU-SIMO systems with ZF receivers", *IEEE Trans. Veh. Technol.*, vol. 62, pp. 44714483, Nov. 2013.
14. Y.C Liang, G.M.Pan, and Z.D.Bai, "Asymptotic performance of MMSE receivers for large systems using random matrix theory", *IEEE Trans. Inf. Theory*, vol. 53, no. 11, pp. 4173-4190, Nov.

AUTHOR DETAILS

Shraddha Kharat received her B.Tech. degree in Electronics and Communication engineering in 2013 from SNDT Women's University, Mumbai, India and currently pursuing M.Tech. degree in Electronics and Communication engineering from the same university.

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